AMENDMENT 0001
BAA 07-029
RESEARCH AND DEVELOPMENT (R&D) AND EXPERIMENTATION ON THE USS ARLEIGH BURKE (DDG 51) FLIGHT IIA CLASS SHIP

The purpose of this Amendment is to provide the following information and documentation:

Attachment (1): Questions and Answers – 3 Pages

Attachment (2): DDG-51 Fuel Efficient and Power Dense Demonstrator Industry Day Attendee List dated May 24th, 2007 – 1 Page

Attachment (3): Government Furnished Information (GFI) for DDG51 Fuel Efficiency BAA – 6 Pages

Attachment (4): Integrated Propulsion Cross-Connect for the DDG-51 – 21 Pages

AMENDMENT 0001
QUESTIONS AND ANSWERS

QUESTION 1: When will the slides that were presented for the Industry Day be available?

RESPONSE: All background information from the Industry Day slides has been incorporated into the BAA. In addition, all other information in the slides concerning proposal dates, format, etc has been superseded by new information published in the BAA.

QUESTION 2: When will the DDG51 Flight IIA power versus fuel consumption curve be available?

RESPONSE: Please refer to Attachment (3).

QUESTION 3: What is the typical power profile of a DDG51 during operation?

RESPONSE: Electrical and propulsion are attached, use the Condition 3 number for electrical. Please refer to Attachment (3).

QUESTION 4: What should we use for the cost range of fuel in performing our ROI analysis?

RESPONSE: Instead of a range, a single value of $100/bbl has been determined.

QUESTION 5: What is the maximum critical load that an energy storage device would need to support if the DDG51 were to go to SGO? Essentially we are looking for how long the critical ships loads, once other loads are shed, would need to be maintained while the 2nd GTG comes on-line.

RESPONSE: 2500kWe for 10 minutes

QUESTION 6: I was unable to attend the meeting but I was wondering if I could get copies of any presentations, materials, and attendee lists that were made available during the meeting?

RESPONSE: Please refer to Question 1.

QUESTION 7: Are copies of the presentations available from the Industry Day held on May 24th?

RESPONSE: Please refer to Question 1.

QUESTION 8: Is an attendance list available from the Industry Day?

RESPONSE: Please refer to Attachment (2).

QUESTION 9: Is a BAA still planned and if so, when is it to be released?

RESPONSE: The BAA has been released.

QUESTION 10: Are you accepting white papers in advance of a BAA being released?

RESPONSE: No, white papers cannot be submitted prior to the release of the BAA.

QUESTION 11: It was mentioned that the slides from the DDG51 fuel savings industry day would be available on ONR's website. I could not locate them. Can you find out the status?

RESPONSE: Please refer to Question 1.

QUESTION 12: Would it be possible to get an electronic copy of PowerPoint presentation from the DDG-51 Fuel Efficient Demonstrator Industry Day on 5/24/07?

RESPONSE: Please refer to Question 1.

QUESTION 13: Can you provide the deadline for submitting questions? Is it relative to the "official" published BAA date?

RESPONSE: The BAA identifies the deadline for question submissions.

QUESTION 14: We need the following info for DDG-51:

-Typical duty cycle of Auxiliary power demand vs. time for a 1 year cycle. If not 1 year whatever can be provided.

RESPONSE: This answer is in the BAA; the response to this question will be provided via the website.

QUESTION 15: Is it possible to obtain copies of any presentation materials used to brief the attendees at the workshop?

RESPONSE: Please refer to Question 1.

QUESTION 16: Under Award Information, it states that the total estimated budget for this BAA program is nine (9) million dollars. Over what time period does this cover? E.g., is this the budget for the first year?

RESPONSE: The anticipated total amount of funding for this entire BAA program is $9M. The timeframe for the program is (2) years ending in 2009. The Program Office may issue a sole or multiple awards under this BAA.

QUESTION 17: …is there technical information available…such as:

- (a) VAMOSC data on fuel usage?
- (b) Current gensets and KW ratings?
- (c) Speed time profiles and typical engine configurations over the speed range?
- (d) Information on MRG?
- (e) Electric Load data?

- (f) Information on Master Equipment Lists?

RESPONSE:

(a) There is no VAMOSC data, however utilize Government Furnished Information (GFI) for DDG51 Fuel Efficiency
(b) Utilize GFI for DDG51 Fuel Efficiency
(c) Information unavailable
(d) Information unavailable
(e) Information unavailable
(f) Information unavailable

<u>QUESTION 18:</u> On page 6 of BAA 07-029, are the page counts listed in the "White Paper Content" section requirements or only guidelines provided 10 page total limit observed?

RESPONSE: The page counts identified within the BAA are requirements.

DDG-51 Fuel Efficient Power Demonstrator Industry Day - 24 May 2007 - Washington, DC

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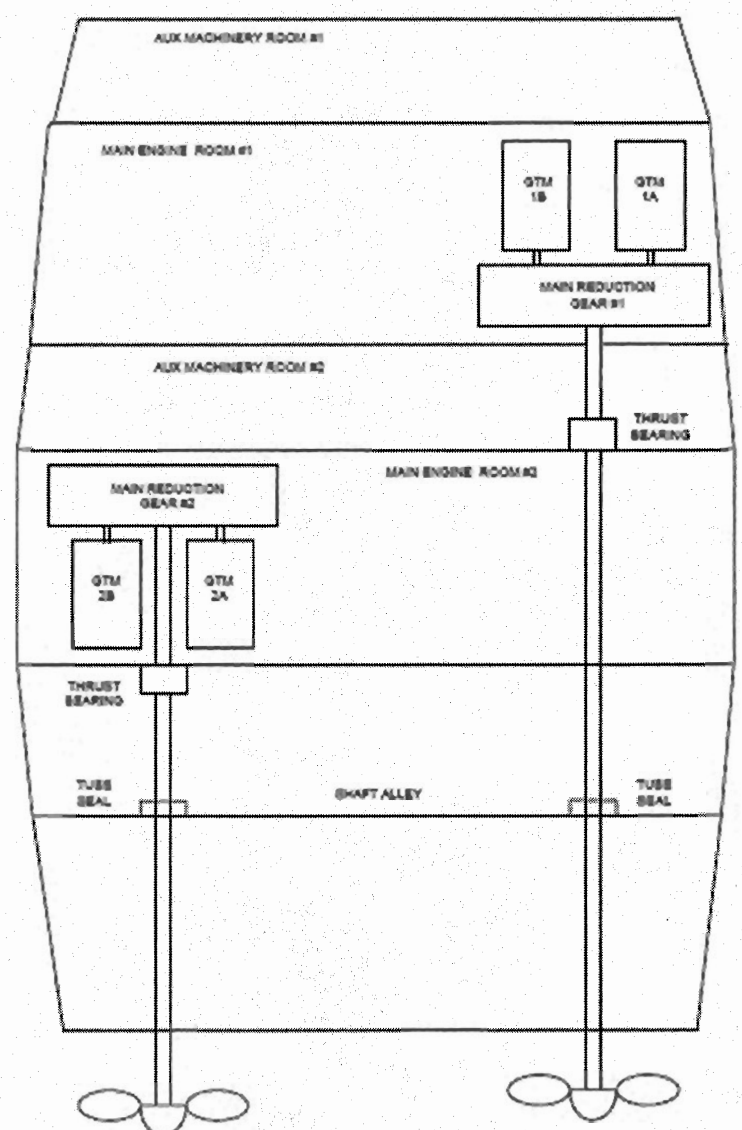
ATTACHMENT 2

GFI for DDG51 Fuel Efficiency BAA

Preferred assumptions and publicly available information

Referenced from:
http://www.usna.edu/EE/ee331/Handouts/Electric_Drive.pdf

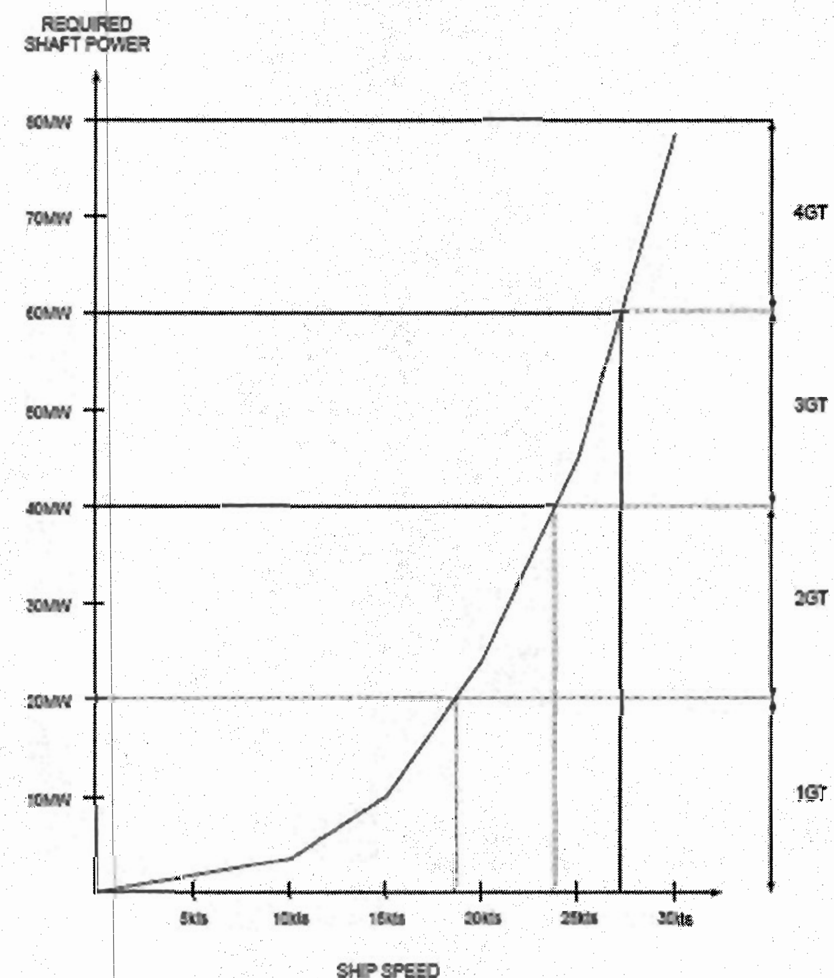
Propulsion Machinery Arrangement:



ATTACHMENT 3

Resistance Calculations (Speed-power curve):

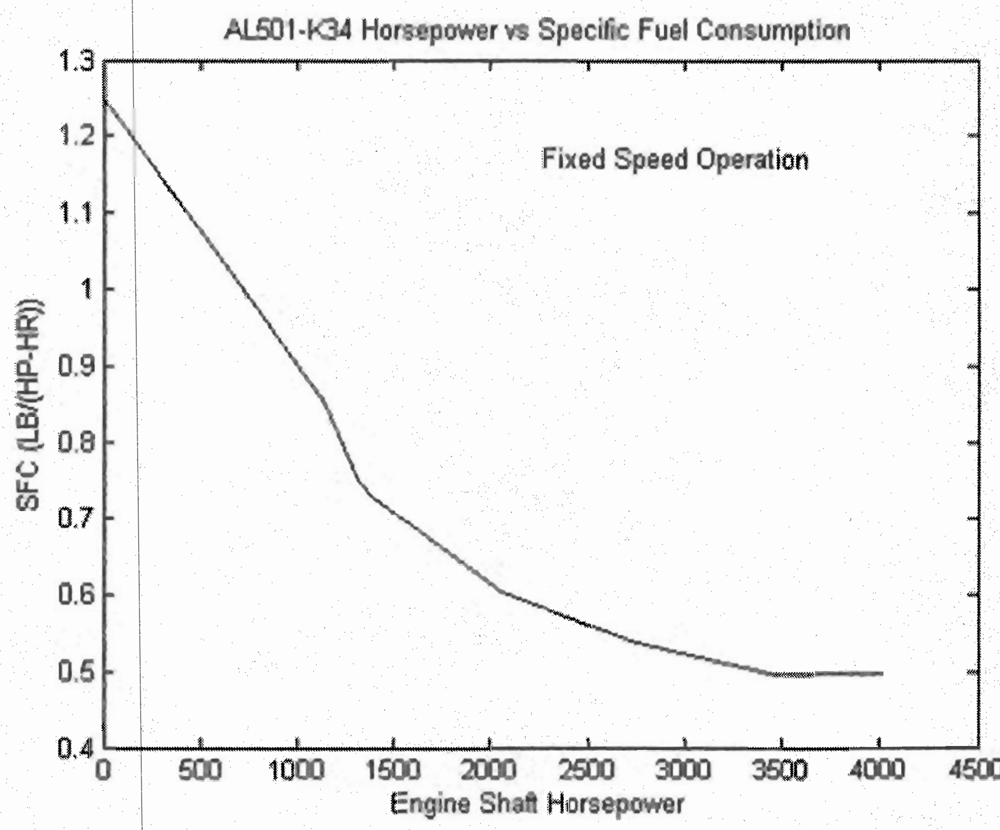
Referenced from:
http://www.usna.edu/EE/ee331/Handouts/Electric_Drive.pdf



Fuel Maps:

Allison 501 engines

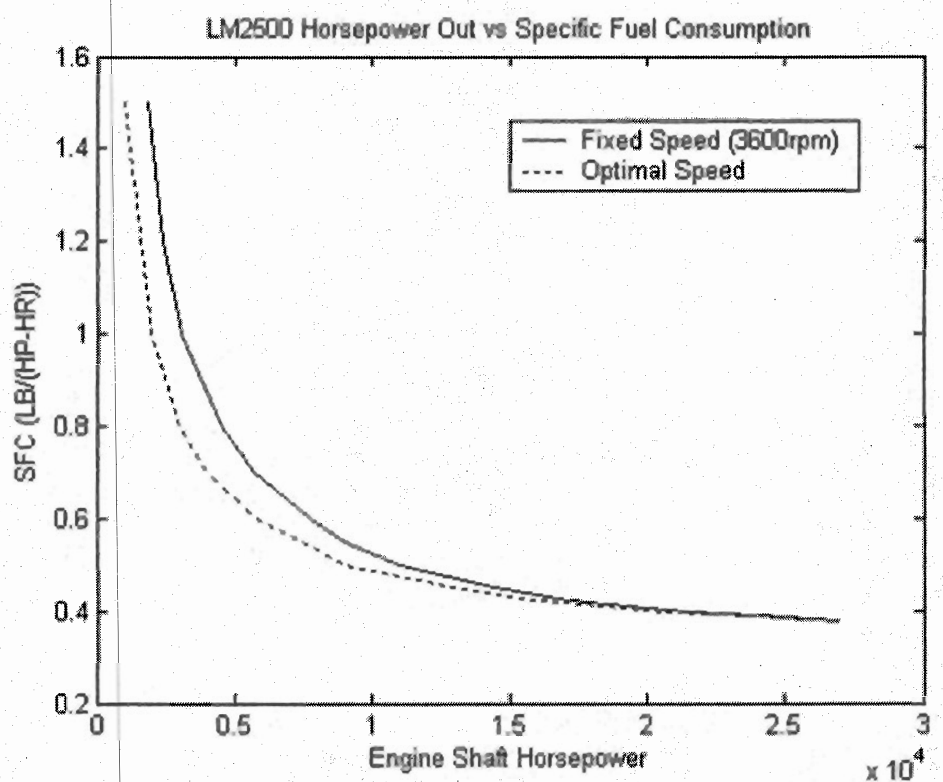
Referenced from:
http://www.usna.edu/EE/ee331/Handouts/Electric_Drive.pdf



LM-2500 engines

Referenced from:
http://www.usna.edu/EE/ee331/Handouts/Electric_Drive.pdf

Use Fixed Speed



<u>Electrical Loading:</u>

Reference
http://dspace.mit.edu/bitstream/1721.1/36067/1/33950380.pdf

Use 2525kW for Electrical Loading

Defined Operating Hours/year :

Use 50% time at sea or 4000 hrs/year

Defined Time at Speed and Plant line-ups:

Typical for Medium Sized Ship

Speed Knots	Time (%)	Time (Hrs/yr)	A ME (% time)	B 2 ENG (% time)	C 4 ENG (% time)
6	10	0	10	30	60
8	18	0.0	20	50	30
9	7	0.0	20	60	20
11	8	0.0	30	50	20
13	10	0.0	30	50	20
15	14	0.0	30	50	20
17	13	0.0	30	50	20
19	11	0.0	30	50	20
21	4	0.0	10	70	20
23	3	0.0	0	80	20
FP	2	0.0	0	0	100
Total	100	0	--	--	--

MECHANICAL DRIVE

— ME (Most Economical) = Trail Shaft

— 2 ENG (Split Plant) = 2 propulsion GTMs (1/shaft) and 2 GTGs

— 4 ENG (Full Plant) = 4 propulsion GTMs (2/shaft) and 2 GTGs

CASE 1

— ME can be single engine per ship.

— 2 engine can be 1 engine for propulsion and 1 engine for ship service (single engine for ship service if propulsion derived ship service can carry ½ ship service load)

— 4 engine is 4 propulsion GTs and 2 GTGs

CASE 2

— ME is minimum 2 engines, any type, providing both propulsion and ship service.

— 2 engine can be 1 engine for propulsion and 2 engines for ship service (single engine for ship service if propulsion derived ship service can carry ½ ship service load)

— 4 engine is 4 propulsion GTs and 2 GTGs

Additional Assumptions:

Consider Auxiliary Systems are available

Auxiliary Drives will not be required to start from Stop

Two sources of ship power are required

Time of two minutes for LM2500 and Allison 501 from Stop to Available Power

Grade B shock requirements for all equipment, except interface connections

Assume a Controllable Pitch Propeller

Assume best case for ship speed control (variable or fixed pitch on the propeller) when using Auxiliary Drives

ATTACHMENT 4

"INTEGRATED PROPULSION CROSS-CONNECT FOR THE DDG-51"
TECHNICAL PAPER

DISCLAIMER: The following technical paper is provided as an example of a DDG51 potential fuel savings application. The opinion and conclusions of the authors do not necessarily represent the opinion and conclusions of the U.S. Navy and may not have direct bearing on the outcome of this BAA effort. In addition, the data utilized for calculations within the technical paper do not reflect the information requested to be used by this BAA.

INTEGRATED PROPULSION CROSS-CONNECT for the DDG-51

Timothy Doyle, Timothy Nixon, Henry Robey
Alion Science and Technology

David Clayton, Thomas Martin
Naval Sea Systems Command

ATTACHMENT 4

SUMMARY:

An electric "Cross Connect" system is one promising option for increasing fuel efficiency and ship service power capacity on a DDG 51 (Guided Missile Destroyer) Class twin screw surface combatant.

The "Cross Connect" could reduce the per ship annual propulsion fuel consumption by an estimated 10,500 Bbls (10-11%), compared to "Split Plant" operation. Fuel benefits follow because a power linkage between port and starboard engine rooms would permit Propulsion Gas Turbines (PGT's) to be operated at more favorable efficiencies. Improvements in survivability, noise signature and machinery maintenance costs would also be expected. At low speed cruise or loiter conditions, where the available power of even one propulsion engine greatly exceeds demand, propeller shafts could be electrically driven from the ship service (SS) buss to further improve fuel efficiency.

Significant additional fuel savings, in the range of 7000 Bbls (7-8%), would result if the electrical generating capacity in "Cross Connect" circuitry was also made available to either provide or backup ship service power. This system, which can be considered an "Integrated" "Cross Connect", would allow ships power to be generated by more economical propulsion engines and/or permit Ship Service Gas Turbine Generators (SSGTG's) to operate without a "rotating reserve" efficiency penalty. Under these conditions, the "integrated" system could deliver fuel savings approaching 17-18%.

When a "Cross Connect" equipped DDG is compared to one which maximizes use of "Trail Shaft" operations, the improvement in propulsion fuel economy alone is considerably lessened---a 2% savings is projected. Total benefit, however, could climb back to the 9-10% range with an "integrated" system, which uses the "Cross Connect" hardware to supply ship service power.

The "Cross Connect" concept examined here would use electric machines coupled to the Main Reduction Gearbox (MRG) in each propulsion shaft line. Machines of approximately 6MW (Megawatts) capacity, would allow the maximum available power from a single operating propulsion turbine to be split between engine rooms, permitting twin screw operation to ship speeds of 18-20 knots. Operating as generators, machines of this size would also represent a significant additional source of ship service power over the full speed range of the ship. Such additional capacity might be necessary to support future combat system upgrades.

SCOPE:

Table 1 identifies some of the options available for increasing the fuel efficiency and ship services power capacity in DDG 51 Surface Combatants.

TABLE 1: ENERGY EFFICIENCY AND POWER UPGRADE OPPORTUNITIES

Potential DDG51 Improvements	Propulsion Energy Efficiency	Ship Service (SS) Energy Efficiency	Ship Service Power Upgrade
Fuel Efficient SSGTG		✓	
Energy Storage (1 SSGTG OPS)		✓	
High Power SSGTG		✓	✓
Propulsion Cross Connect (1 PGT Cruise)	✓		
SS Derived Propulsion (Low Speed Cruise)	✓		
Propulsion Derived SS		✓	✓

The first option proposes a more fuel efficient ship service prime mover. Substituting a free turbine engine, as an example, for the currently used, single spool, fixed speed units, could improve the part power efficiency of SSGTG's----a converter on the generator output could maintain power quality during system power transients. Equipping SSGTG's with an energy storage-converter system sized to "ride through" an engine-generator failure, and bring a substitute unit on line, would eliminate the need for a rotating backup engine, and its associated fuel penalty. A higher power SSGTG, perhaps exploiting high speed free turbine-generator to stay within space and weight allowances, would certainly provide additional ship service capacity. With energy storage or a similar concept, fuel efficiency might also be increased. Again, a power converter would be used to provide frequency control and power quality.

This report focuses on the last three "improvement" options in the Table 1 matrix, both separately and in combination. The improved fuel economy possible by equipping a DDG 51 Class mechanical drive surface combatant with an electrical "Cross Connect" system in both stand alone and "integrated" configurations is estimated. The machinery considered electrically connects port and starboard propulsion shaft lines, as well as providing a bidirectional power interface between the "Cross Connect" circuitry and the ship service power system. This latter feature permits propulsion from the ship service buss, as well as generation of ship service power from a propulsion turbine source.

This analysis projects and compares fuel consumption characteristics of a "Cross Connected" and a conventionally equipped DDG Baseline ship. Fuel rate estimates over the full ship speed range are calculated, assuming two DDG Baseline operating modes, one confined to "Split Plant" operation, and one which takes maximum advantage of the economy provided by "Trail Shaft". Annual fuel usage estimates are also provided using a representative mission speed-time profile.

Both "Cross Connect" and Baseline powering and fuel rate performance are based on, and traceable to, reported trial data from the DDG 79, the USS Oscar Austin (Ref. 1). Total ship fuel rates are presented, with the ship service contribution based on a 24 hour average load of 1900 KW. All calculations assume two sources of ship service power are always required and on-line.

The results presented here reflect a refinement and extension of earlier work reported in Ref. 2. The prior study provided an annual fuel consumption comparison between a "Cross Connected" DDG and a "Split Plant" Baseline----no "Trail Shaft", or ship service integration options were evaluated.

BACKGROUND:

Fuel usage in the Navy's Fleet of Surface Combatants is substantial, and costs are growing with increasing crude oil prices. Much of the high unit consumption follows from the very high power to weight ratios typical of twin screw DDG's and CG's (Guided Missile Cruiser). Installed propulsion power must be adequate for flank speed operation, yet a very small fraction of underway time is spent at these high power conditions. As a result propulsion gas turbines are most often operating well below rated power, where the fuel efficiency of simple cycle engines is poor. A similar part power economy penalty accompanies the operation of ship service turbine generators, when additional lightly loaded units must be maintained on line to provide continuity in the event of a turbine generator failure.

A typical twin screw DDG machinery arrangement is shown in Figure 1. Included are two pairs of General Electric LM2500 Propulsion Gas Turbines (PGT's), each pair driving a low speed controllable pitch propeller through locked train double reduction gearing. Propulsion engines are rated at approximately 26 KHP. Ships power is provided by 3 Allison Ship Service Gas Turbine Generators (SSGTG's), each capable of delivering 3000 KW (Kilowatts). Figure 2 shows how fuel economy degrades at low engine power levels for propulsion and ship service size gas turbine engines (Ref. 3, 4).

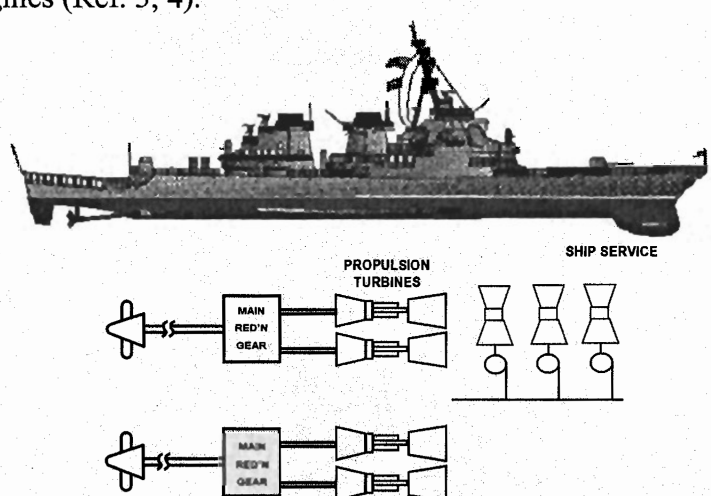


FIGURE 1: DDG BASELINE POWER SYSTEM

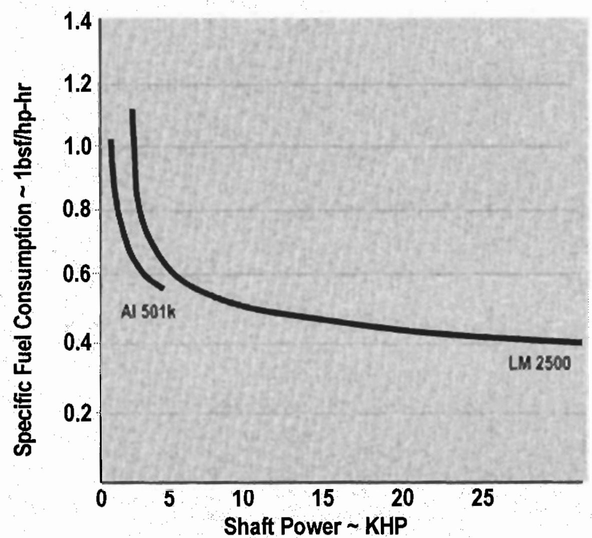


FIGURE 2: FUEL CONSUMPTION (PROPULSION & SHIP SERVICE ENGINES)

Propulsion fuel economy penalties are most severe in the cruise speed range (20 knots and less) when port and starboard propellers are each powered by separate turbines---under these "Split Plant" conditions propulsion turbine fuel efficiency would have degraded 30% or more below full power design values.

A portion of the "Split Plant" fuel penalty can be recovered by "Trail Shafting", which involves letting one propeller windmill or "trail" while "over" powering the second. The fuel efficiency benefits of operating on a single, more highly loaded propulsion engine have been shown to more than compensate for the increased hydrodynamic losses of asymmetric powering. For this reason, pressures to reduce fuel usage are resulting in increasing use of "Trail Shafting" in the existing fleet.

"Trail Shafting" does not require modification of DDG propulsion hardware, an obvious and significant advantage. Disadvantages, however, also accompany this mode of operation. These include increases in ship drag and required power from the operating engine, the need for continuous rudder correction, appreciably reduced maneuverability, and increases in the ship's noise signature.

DDG OPERATING BASELINES:

A classic displacement hull cubic power-speed relationship can be applied to the DDG over the greater part of its speed range. The DDG trial data (Ref. 1) for the USS Oscar Austin (DDG-79), presented in Figures 3 and 4, illustrates the impact of speed on total fuel consumption. Three separate propulsion machinery system line-ups are presented: (1) "Full Power", 2 PGT's powering each shaft, (2) "Split Plant", 1 PGT driving each propeller, and (3) "Trail Shaft", 1 PT powering one shaft with the non-powered prop "wind milling" in a minimum drag mode. In all cases, 2 SSGTG's are on-line to assure continuity of ship service power, even through one would be adequate to provide the 24 hour average load of 1900KW. The contribution of these 2 SSGTG's is included in the total fuel rate.

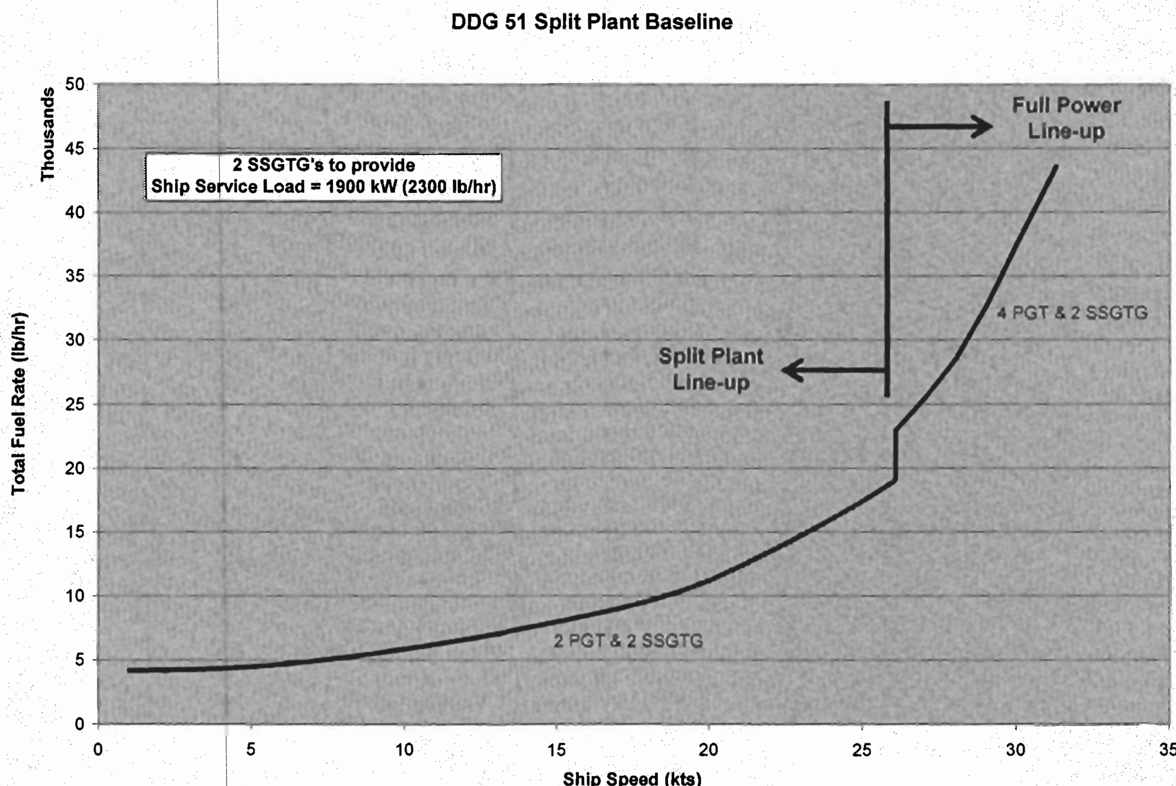


FIGURE 3: Fuel Rates for the Split Plant Baseline

If it's required that both propellers always be powered the fuel rate characteristic shown in Fig 3 applies—in this report this configuration will be referred to as the "Split Plant" Baseline. Four propulsion turbines are required at very high ship speeds. A step change occurs in the 26 Knot range when two turbines can be placed off-line, and we can transition from the "Full Power" to the "Split Plant" mode. The initial higher unit loadings of the remaining two operating units demonstrate the expected fuel efficiency advantages, illustrated by the step change shown. As ship speed and required propulsion power falls further, engine fuel consumption will also continue to decline and approach the idle fuel rate. Low speed operation requires propeller pitch reduction, with the pitch value selected to deliver the intended speed at the most economical fuel rate.

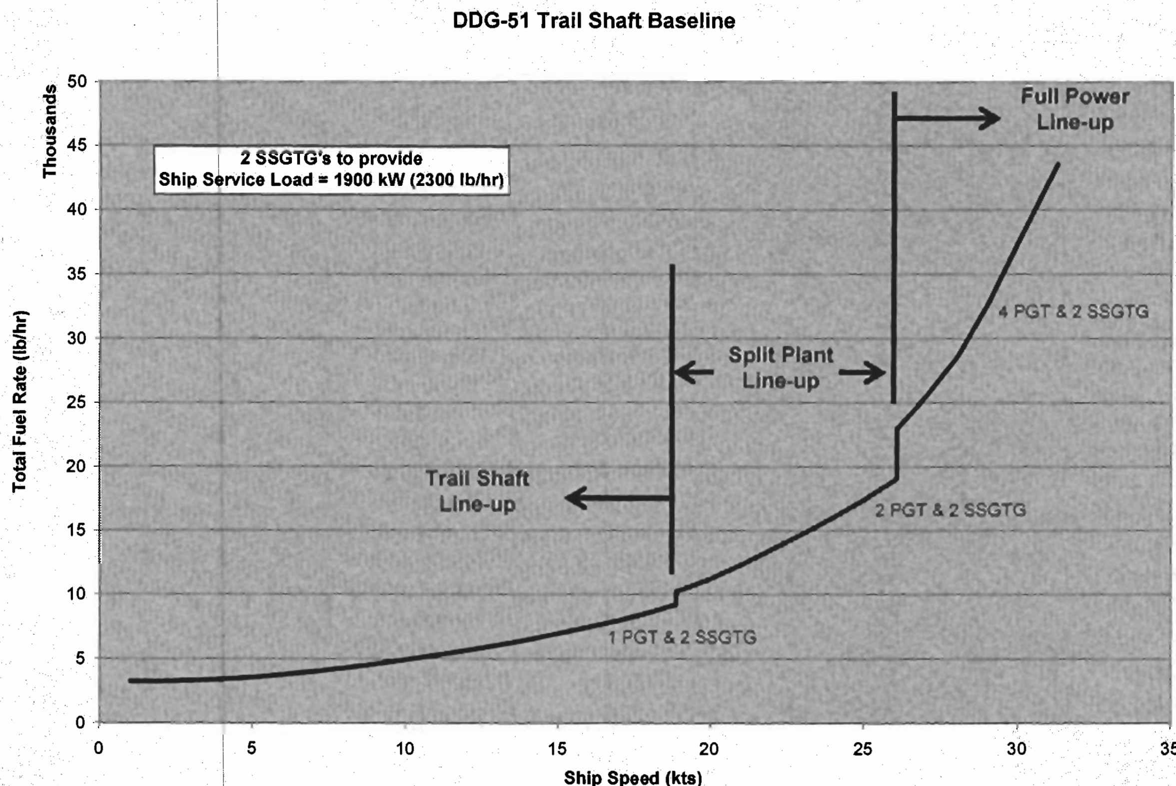


FIGURE 4: Fuel Rates for the Trail Shaft Baseline

The fuel rate curve of Figure 4 shows operation in the "Trail Shaft" mode, referred to in this report as the "Trail Shaft" Baseline. "Trail Shaft" operation can be considered at ship speeds below 19 knots, where required propulsive power is within the capability of a single PGT, and minimum fuel consumption is the number 1 priority.

The differential fuel rate curve of Figure 5 graphically illustrates the significant difference between the "Trail Shaft" and "Split Plant" fuel rates. The improved economy provided by "Trail Shafting", as discussed above, follows from the more favorable engine loading. In the "Trail Shaft" operating mode maximum pitch is selected for the trailing propeller to minimize drag. The pitch on the driven shaft is set to deliver required thrust and ship speed at the engine speed delivering the best turbine fuel economy.

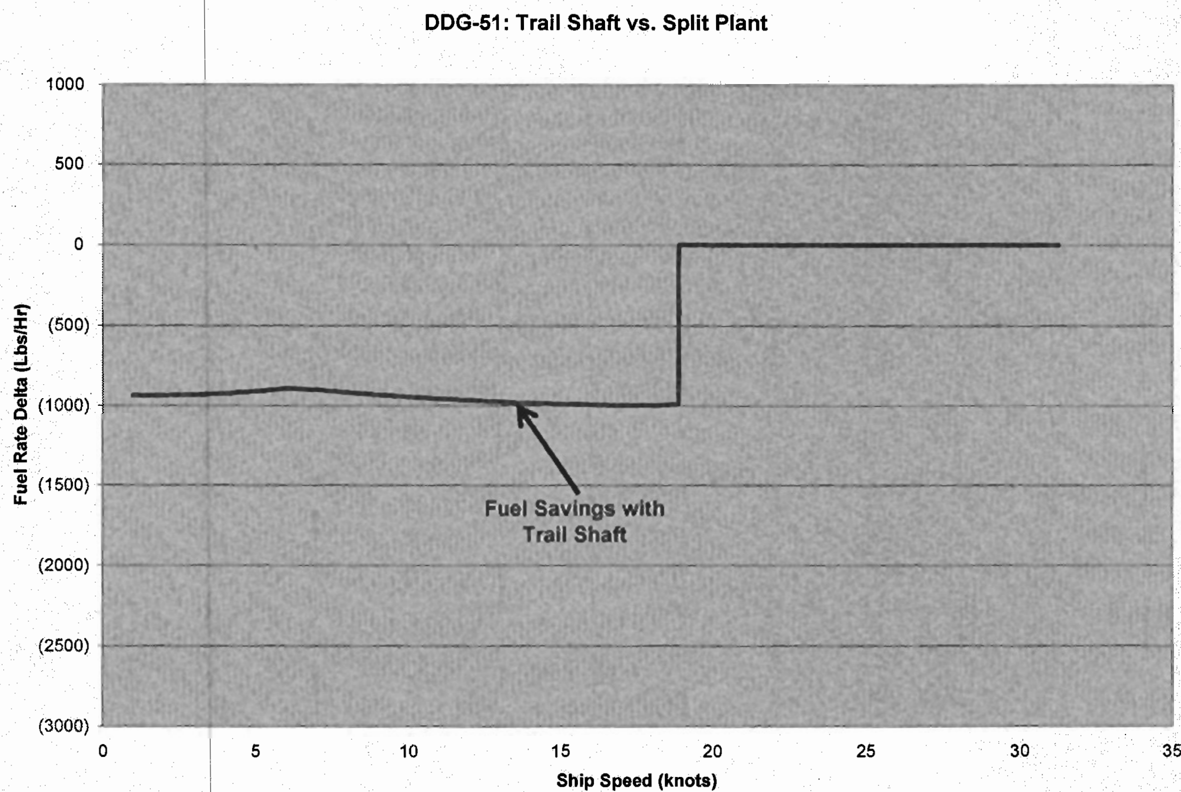


FIGURE 5 Differential Fuel Rate, Trail Shaft Baseline vs. Split Plant Baseline

ELECTRICAL PROPULSION CROSS CONNECT:

The "Cross Connect" system illustrated in Figure 6 would provide the desired power path between port and starboard engine rooms. Although other benefits and opportunities would result, the principal intent here is to reduce fuel consumption under cruise conditions by permitting both screws to be powered from any one of the four installed propulsion engines. The single on-line engine, operating at a much higher fraction of its design power, would require significantly less fuel than two lightly loaded units operating in the "Split Plant" configuration, even after accounting for the additional power lost in the transfer equipment.

There are several possible power take off points on the combining, double reduction gearing typical of surface combatants, each dictating the torque-speed interface characteristics that the cross connect machinery must match. The concept presented here for potential application in the DDG 51 class, would use electric machines coupled to the first reduction shafting of each propulsion gearbox. A similar arrangement was proposed in an earlier paper as a way of powering auxiliary generators for high energy combat systems (Ref. 5). Significant modifications internal to the gearbox would not be expected.

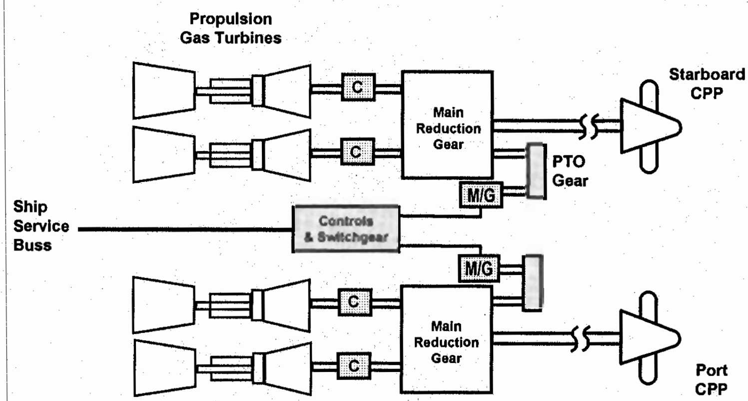


FIGURE 6: CROSS CONNECT ADDITIONS TO BASELINE PLANT

Identical electric machines of approximately 6MW capacity, one operating as a generator, and the other as a motor, let power from a single operating turbine to be split between engine rooms, permitting twin screw operation to ship speeds of 18-20 knots. The 6 MW machine size reflects the maximum practical power flow through the cross connect circuitry consistent with limiting the single driving propulsion turbine to its full power torque rating. Maximum power, in this case, translates to maximum potential fuel savings. The favorable effect "Cross Connect" operations would have on engine fuel economy is shown in Figure 7.

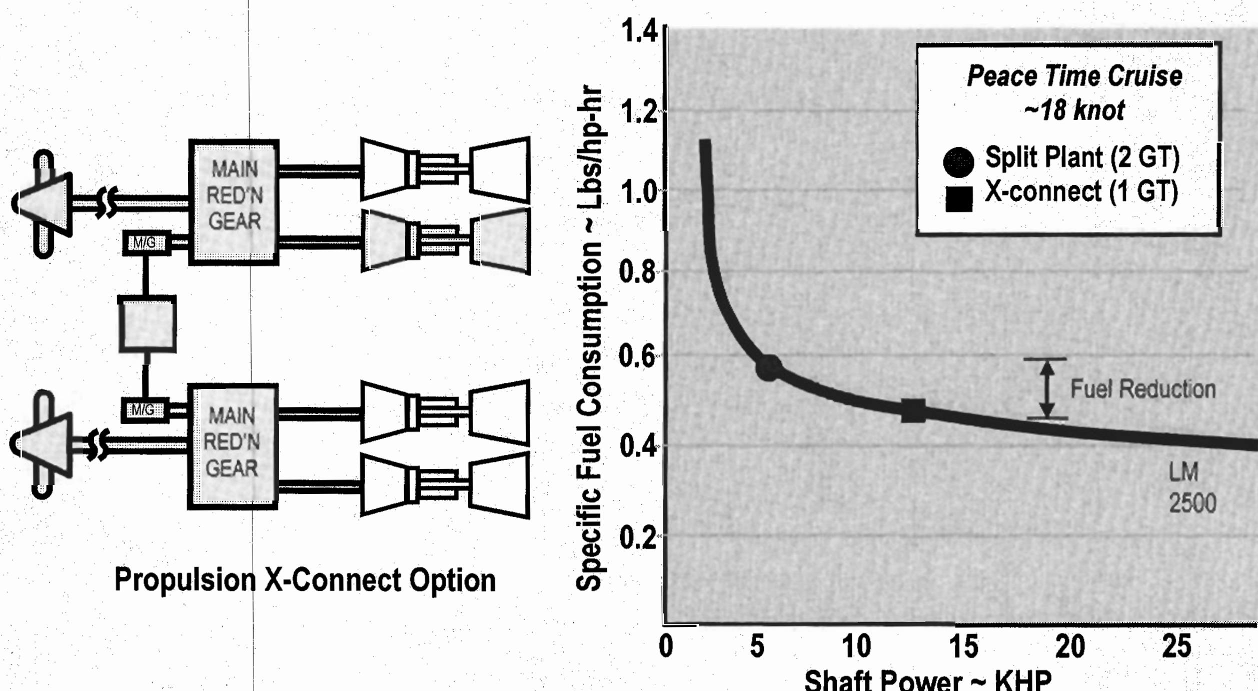


FIGURE 7: FUEL ECONOMY BENEFITS OF SINGLE ENGINE CRUISE

The controller processes all power flowing in the "Cross Connect" circuitry, allowing the orderly acceleration or deceleration of the driven machine, permitting "synchronous" operation when identical shaft RPMs (Revolutions per Minute) are called for, or providing for differential speeds for steering or efficient course maintenance in a seaway.

The controller could also be configured to accept and condition ship service power to drive both gearbox connected machines as motors. This would make sense at low speed cruise or loiter conditions, where the available power of even one propulsion engine would greatly exceed demand. To illustrate, approximately 750 KW delivered to each gearbox will propel the ship at 10 knots. Required propulsion power will continue to reduce exponentially as ship speed decreases further.

This system lineup would generate additional fuel savings beyond single main engine "Cross Connect", since propulsion power would now be generated at the fuel rate of a turbine much better matched to the load (see Figure 8). An acoustic advantage would also result since shaft speed and thrust would be electrically controlled, and the Controllable Pitch Propeller (CPP) could remain at full pitch. This ship service driven propulsion configuration has similarities with the LHD 8 propulsion plant in both content and intent (Ref. 6).

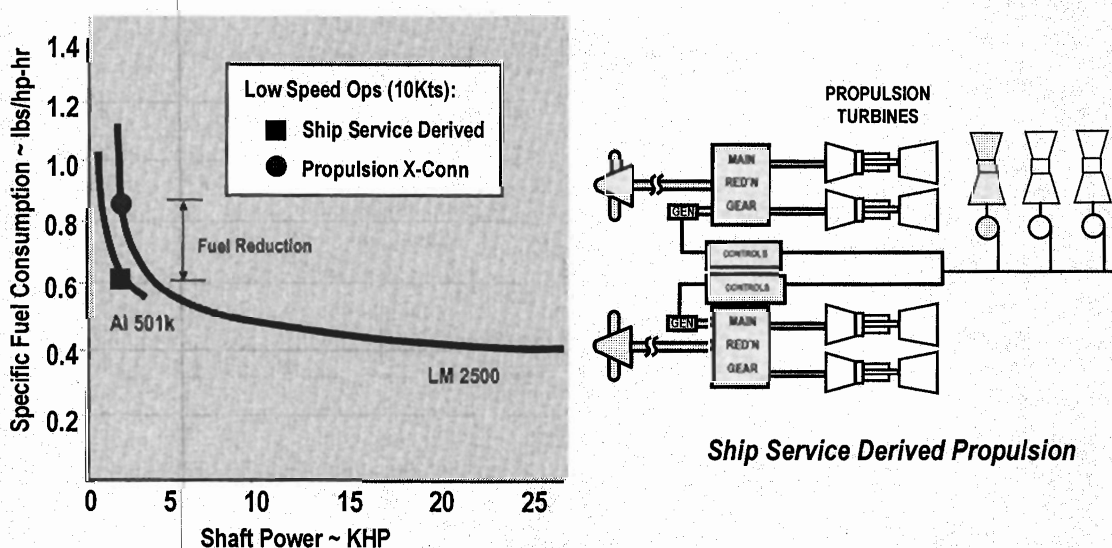


FIGURE 8: PROPULSION FUEL ECONOMY BENEFITS USING SHIP SERVICE POWER

Detailing the size and performance of cross connect system elements is beyond the scope of this paper. Defining efficiencies of the major equipments is necessary, however, to properly estimate engine powers and resultant fuel rates. For this study the conversion efficiencies of each electric machine, controller, and offset gear were set at 96%, 97%, and 97%, respectively. The power transfer process between port and starboard main reduction gears, therefore, is accomplished at an efficiency of 84%.

Regarding machine size, it is expected the selected location at the high speed/low torque end of the propulsion gearing would permit the most compact designs. The offset gearing could further increase the motor/generator design speeds and power densities, as well as provide some installation flexibility. A variety of technologies and design options could be considered in the machine, control, and transmission equipment.

A clutch disconnect at the MRG interface could allow the added "Cross Connect" equipment to be categorized as "non-mission critical", since a failure need not compromise current propulsion functionality---cost savings would result from a less demanding qualification process, and an increased commercial marine content. Any backfit application will clearly be a challenge, however, especially for the electric machines which must interface with the rotating elements of the propulsion system.

PROPULSION FUEL SAVINGS ESTIMATES:

The reduced fuel rates possible with "Cross Connect" and ship service "propulsion" power are compared with "Split Plant" and "Trail Shaft" baseline operation in Figures 9 through 12. In Figures 9 and 10, comparing "Cross Connect" with the "Split Plant" Baseline, propulsion fuel savings kick in at the higher end of the cruising speed range (18 to 20 knots), with immediate reductions of 10-12% projected over "Split Plant" operation. Progressively better economies are realized at lower ship speeds, 16-20% in the 14 to 16 knot range, and well over 25% at speeds below 12 knots where a ship service engine can be substituted for the LM2500.

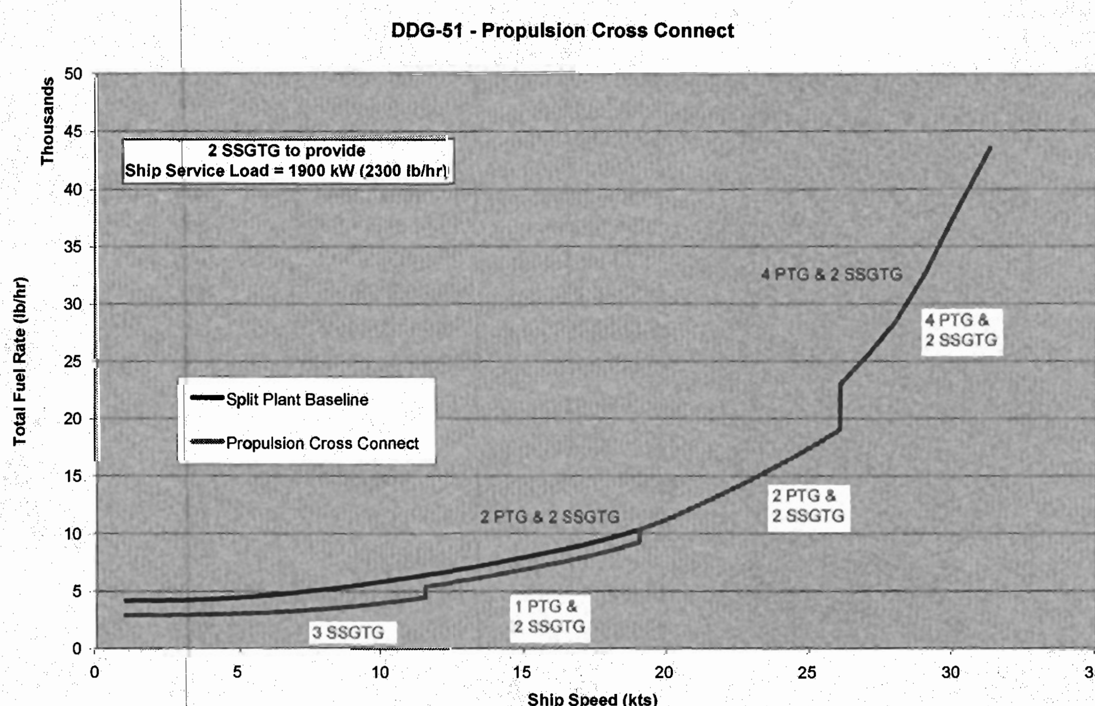


FIGURE 9: Fuel Rates, Propulsion Cross Connect vs. Split Plant Baseline

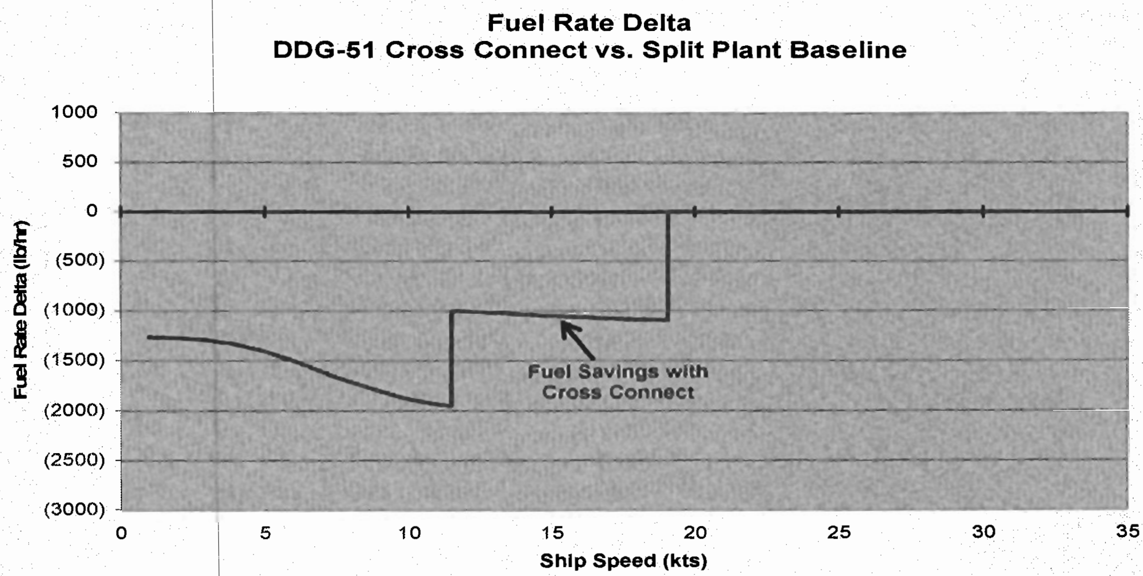


FIGURE 10: Differential Fuel Rate, Propulsion Cross Connect vs. Split Plant Baseline

Potential savings are much reduced when "Cross Connect" is compared with a "Trail Shaft" Baseline, as shown in Figures 11 and 12, since nearly identical fuel rates are demonstrated in the 12-18 Knot range. This results because the hydrodynamic losses (propeller, rudder drag, etc) accompanying "Trail Shaft" operation are not much higher than the gearing and electrical losses of the "Cross Connect" machinery. The power required of the single operating propulsion turbine, therefore, and its fuel efficiency is about the same for each configuration.

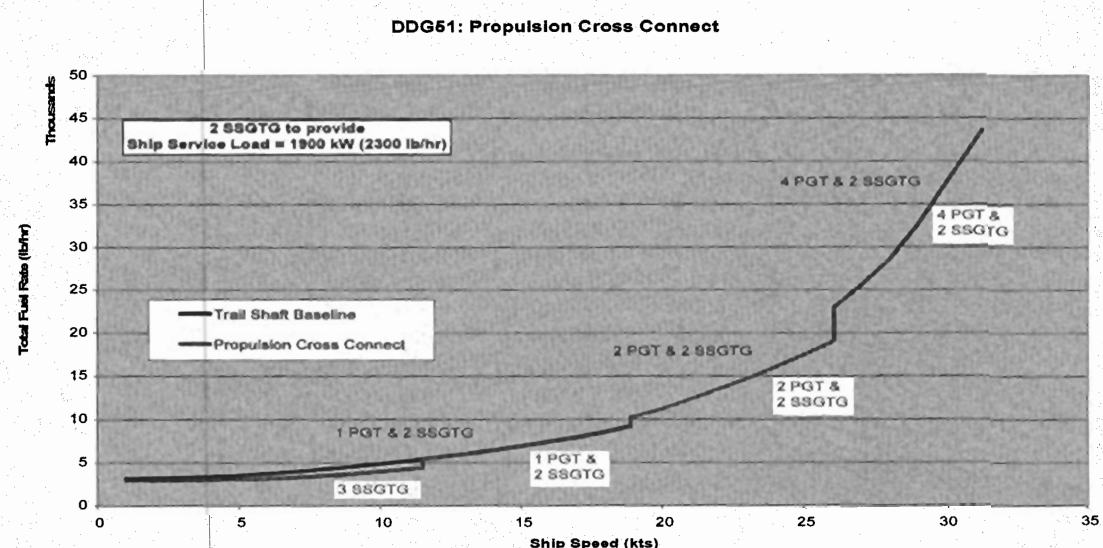


FIGURE 11: Fuel rates, Propulsion Cross Connect vs. Trail Shaft Baseline

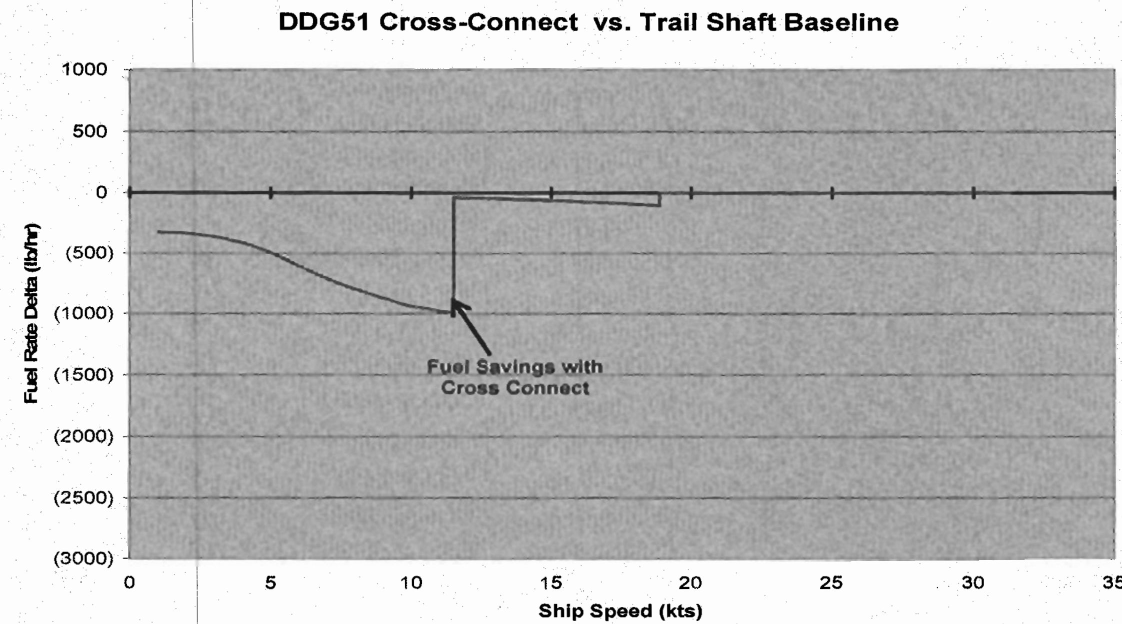


FIGURE 12: Differential Fuel Rate, Propulsion Cross Connect vs. Trail Shaft Baseline

Below 12 knots, however, we could save some fuel (compared to "Trail Shaft") by using ship service power to provide propulsion through the "Cross Connect" machinery. This suggests that design powers (and machine ratings) closer to 1 MW (vs. 6 MW) might be adequate for a "Cross Connect" system designed for low speeds if we were only interested in propulsion fuel reduction. As discussed below, however, higher machine ratings would be necessary to capture potentially significant reductions in ship service fuel consumption.

INTEGRATED PROPULSION and SHIP SERVICE:

If we have a two way power flow option in the propulsion-ship service circuitry we should be able to substantially increase the total ship fuel savings beyond that provided by "Cross Connect" alone, by using the "Cross Connect" machines to either generate or backup ship service power. If , for instance, the "Cross Connect" machine(s) could serve as the "rotating reserve" for the SSGTG system, we could provide the 1900 KW average DDG load with one, rather than 2 SSGTG's----the resultant higher SSGTG loading, as discussed previously, would save substantial fuel.

An even greater fuel savings would be possible at higher ship speeds (i.e. >20 Knots) when the "Cross Connect" equipped ship would be operating in the "Split Plant" mode. Under these conditions, each "Cross Connect" machine could be operated as a generator, providing the required two sources of ship service power. No SSGTG need be on line. Ship service power in this case would be generated at the differential fuel rate of a PGT, and efficiencies approaching diesel engine levels would be expected.

The bi-directional nature of the "integrated" system, together with the demanding power quality requirements of ship service power, would necessitate more sophisticated power conditioning hardware. The "Cross Connect" machines themselves, would also have to be of sufficient size to provide the ship service load, even when turning at the reduced RPM's associated with low ship speeds. Ref. 7 discusses some of the design issues and technology options available to provide this capability. It's also useful to recognize that such a system, although configured here for the DDG 51, would have considerable commonality in objective and technology, with the Integrated Power System (IPS) being developed for the DDG 1000.

INTEGRATED PROPULSION and SHIP SERVICE FUEL SAVINGS:

Figures 13-16 present the fuel savings properties of combined propulsion "Cross Connect" and ship service power systems compared with the "Split Plant" and "Trail Shaft" Baselines.

Examining Figure 13, the full capability of the 4 LM 2500's must be dedicated to propulsion to reach the maximum ship speed. As speed reduces slightly, however, excess PGT power soon becomes available for ship service and the SSGTG's can be taken off line---substantial fuel consumption benefits result, as shown in Figure 14.

A similar transition occurs at the high end of the "Split Plant" speed range with 2 PGT's operating (at approximately 27 knots). Again, a small reduction in ship speed and propulsion power permits the PGT's to again service the ship service load, without any SSGT's needed on line.

The transition to "Cross Connect" propulsion again presents a similar situation, with the exception that one SSGTG must remain on line to provide the required ship service "redundancy". Eventually, in the speed range below 10-12 knots, the most efficient engine line-ups will include only SSGTG's for both ship service and propulsion loads.

The fuel savings potential of the combined, or "integrated" system is evident at virtually all ship speeds, as illustrated in Figure 14.

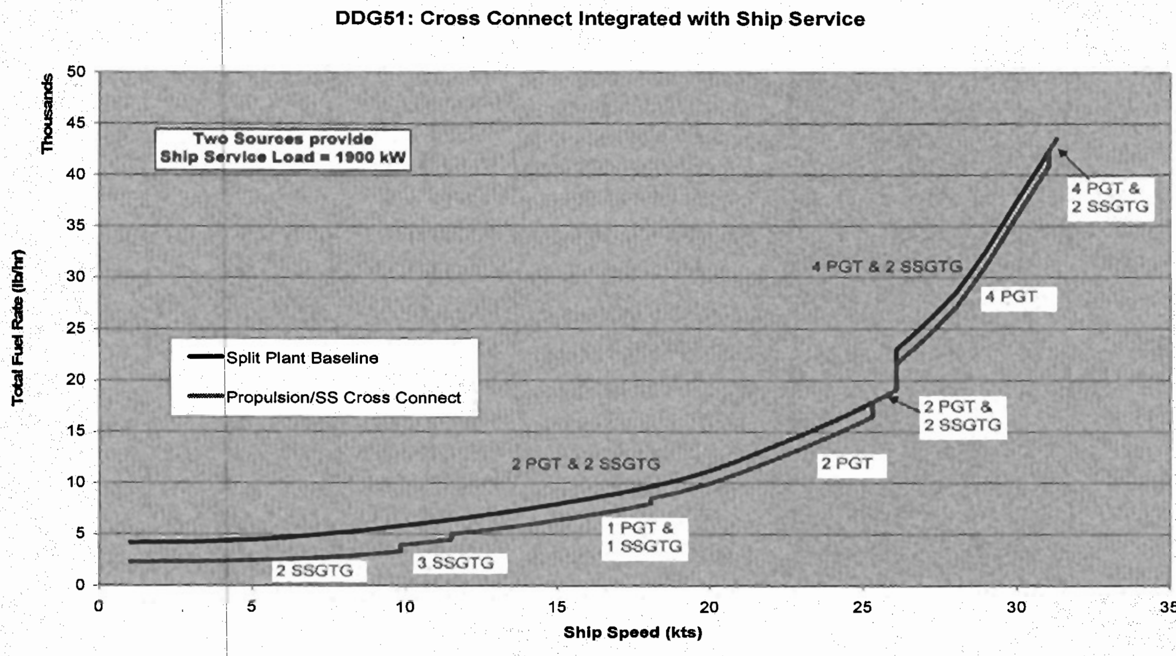


FIGURE 13: Fuel Rates, Integrated Propulsion-Ship Service vs. Split Plant Baseline

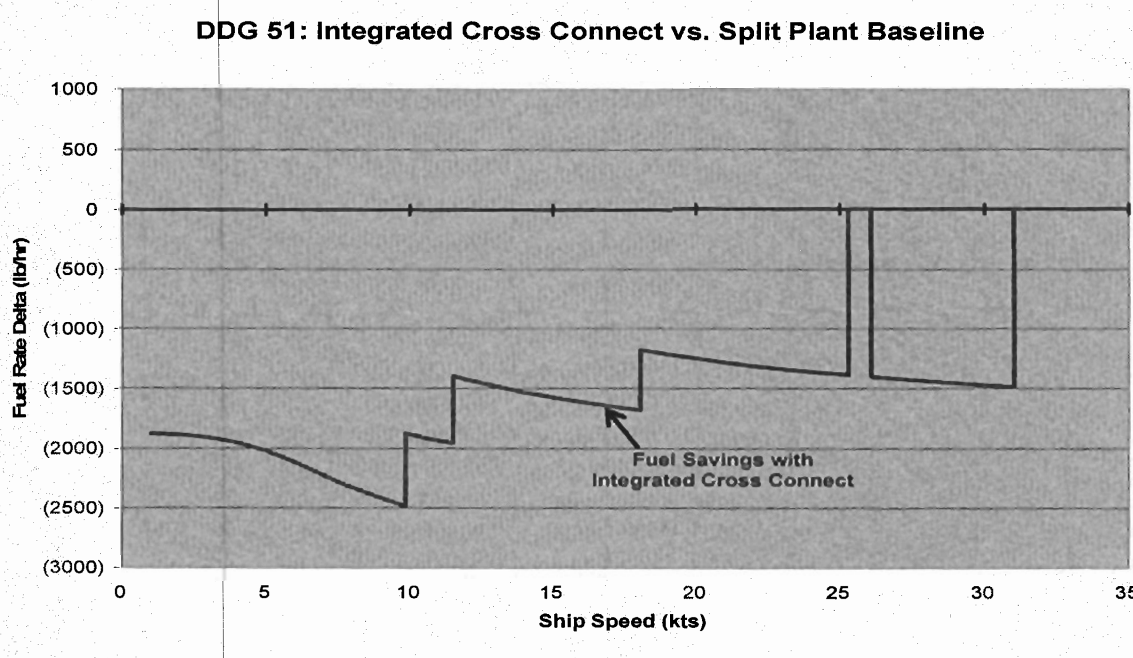


FIGURE 14: Differential Fuel Rate, Integrated Propulsion-SS vs. Split Plant Baseline

When compared with the "Trail Shaft" Baseline, the fuel economy benefits of the integrated "Cross Connect" are understandably reduced at ship speeds below 19 Knots (Figure 15). Substantial savings, nonetheless, are demonstrated across the entire speed range, as illustrated in Figure 16.

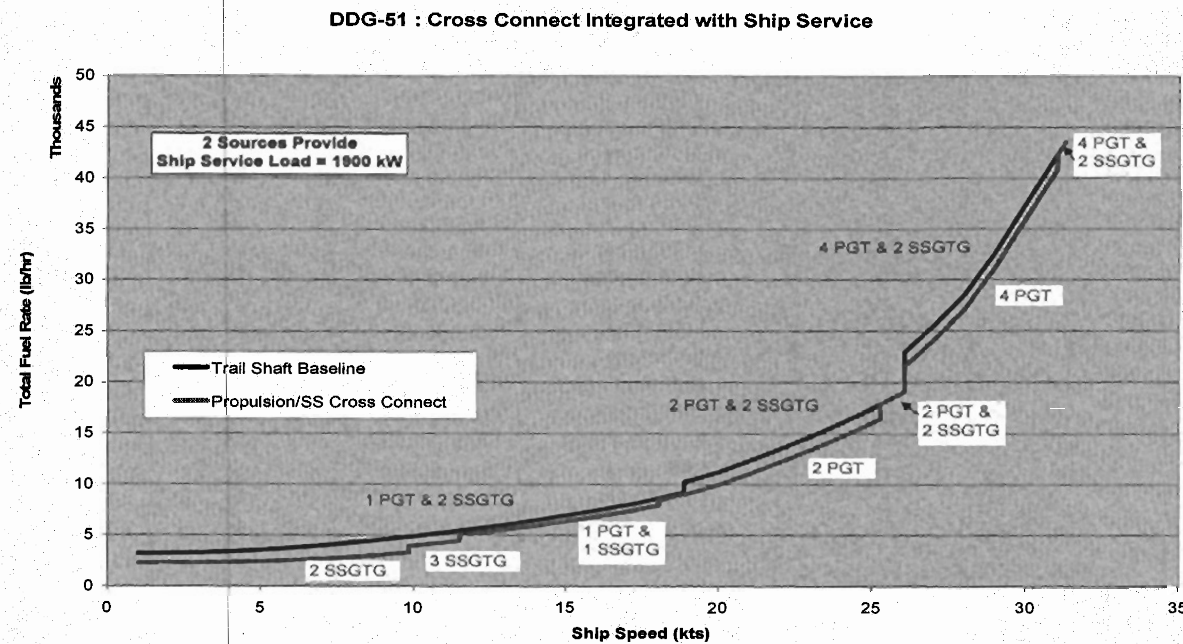


FIGURE 15: Fuel Rates, Integrated Propulsion-Ship Service vs. Trail Shaft Baseline

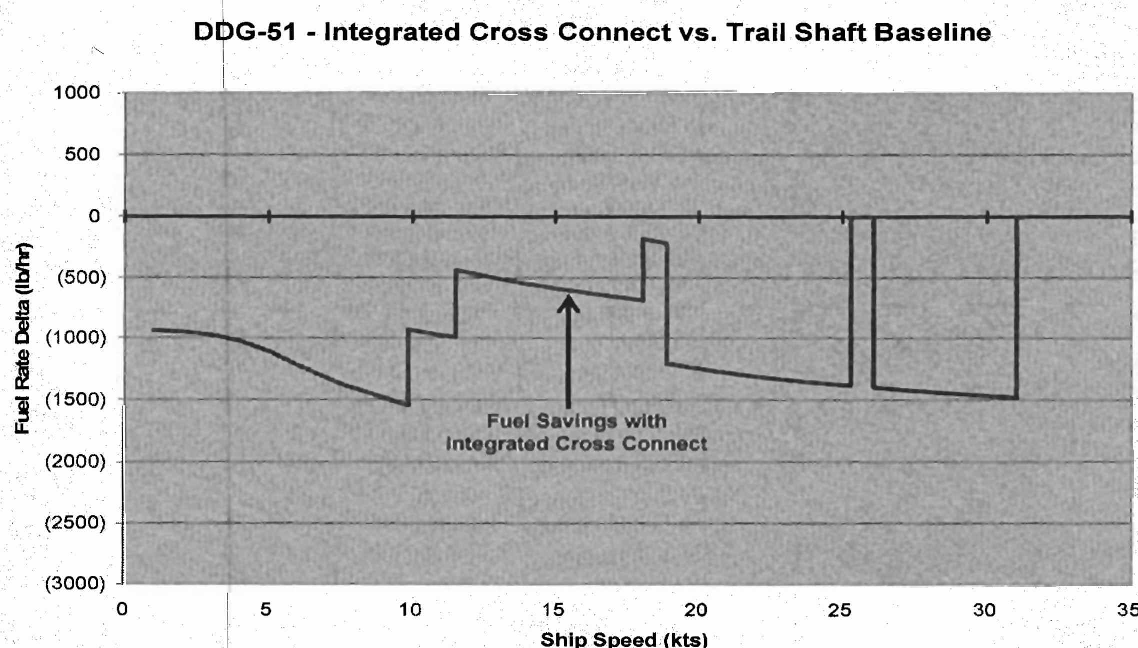


FIGURE 16: Differential Fuel Rate, Integrated Propulsion-SS vs. Trail Shaft Baseline

ANNUAL FUEL CONSUMPTION ESTIMATES:

The representative mission time-speed profile for a DDG, shown in Figure 17 below, allows the reduction in annual per ship fuel requirements to be estimated.

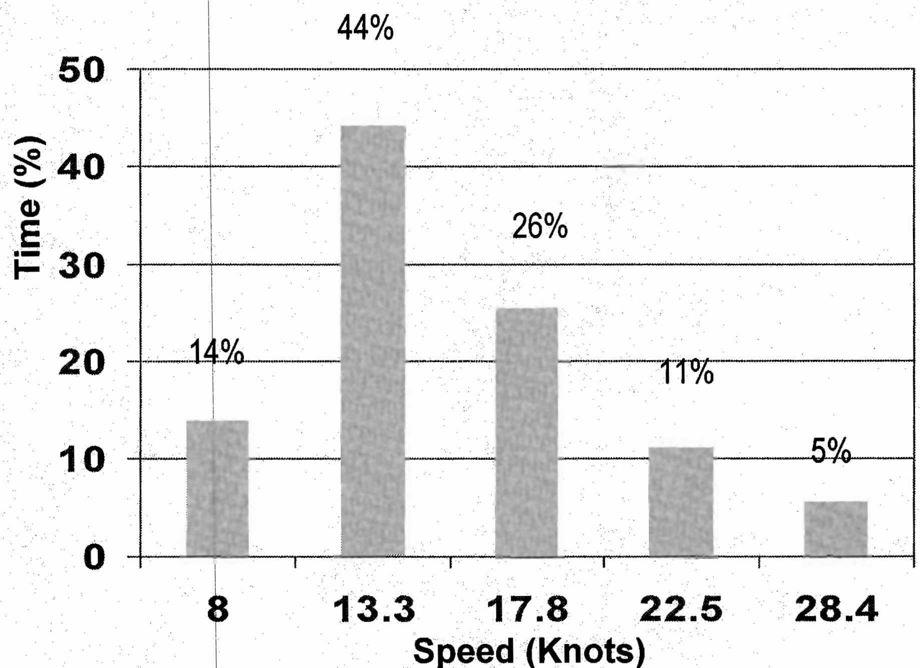


FIGURE 8: REPRESENTATIVE DDG MISSION PROFILE

Results are summarized in Table 1, assuming 3200 at-sea hours per year. Annual fuel usage is presented for the "Split Plant" and "Trail Shaft" Baselines, and the "Cross Connect" systems, one configured for propulsion only, and the other equipped to provide propulsion and generation of ship service power. Percentage reductions over each Baseline are also tabulated.

TABLE 2: ANNUAL FUEL SAVINGS PER SHIP (3200 HOURS UNDERWAY)

SYSTEM	ANNUAL FUEL CONSUMPTION (PROPUL'N + SS)	SAVINGS OVER SPLIT PLANT BASELINE	SAVINGS OVER TRAIL SHAFT BASELINE
SPLIT PLANT BASELINE	101,400 BBLS	-----	-----
TRAIL SHAFT BASELINE	92,600 BBLS	8,800 BBLS (8.7%)	-----
CROSS CONNECT, PROPUL'N ONLY	90,900 BBLS	10,500 BBLS (10.4%)	1,700 BBLS (1.8%)
CROSS CONNECT, INTEGRATED PROPULSION & SS	83,800 BBLS	17,600 BBLS (17.4%)	8,800 BBLS (9.5%)

In all cases, a 1900 KW average ship service load is provided by two on-line power sources to assure continuity to vital loads. Calculations assume "Trail Shaft" and "Cross Connect" operations are employed when ever ship speed /powering characteristics permit, generally at all speeds up to 18-20 knots. Obviously, if the 50+ DDG Fleet could be so equipped, the savings in fuel and operating cost would be very large.

Lower maintenance costs resulting from fewer engine operating hours might also add to the cost reduction picture. If the full potential of electrical "Cross Connect" were applied to this mission profile, for instance, a more than 40% reduction in propulsion engine hours would be realized over "Split Plant" operation. Substantial reductions in SSGT on-line hours would also result from integration of propulsion "Cross Connect" with ship service.

SPECIFIC CONCLUSIONS REGARDING FUEL EFFICIENCY:

- A DDG which maximizes use of "Trail Shafting" (i.e. "Trail Shaft" Baseline) could demonstrate a reduction in Annual fuel use approaching 8-9% compared to one which never operates in the "Trail Shaft" mode (i.e. "Split Plant" Baseline). Since some conditions---difficult maneuvering, battle stations, underway refueling, etc---would preclude use of "Trail Shaft", the 8-9% improvement must be considered an upper limit, not likely to be realized in service.

- A ship with "Cross Connect" equipment designed to increase propulsion fuel efficiency could demonstrate a 10-11% reduction in fuel use compared to the "Split Plant" Baseline----again, this must be considered an upper limit. This significant benefit, however, would shrink to 2% if compared to a "Trail Shaft" ship. In this case, the 2% number would be the lower limit of expected savings.

- A DDG equipped with "Integrated Cross Connect" machinery to both improve propulsion performance, and generate ship service power from the propulsion engines, will maximize the fuel reduction benefit---up to 17-18% improvement over the "Split Plant" Baseline, and at least 9-10% better than "Trail Shafting" alone.

- To maximize the benefits of "propulsion derived" ship service the "Cross Connect" machines in an "integrated" plant should be equivalent, or nearly so, in power generating capacity to the 3000KW SSG's, even when propulsion machinery is operating at the lower end of it's speed range. The machine ratings suggested in this study, approximately 6MW at the 18-20 Knot speed range, should satisfy this requirement. It is recognized, however, that the space constraints of a retrofit application could very likely limit "Cross Connect" machine size and power level---the resultant reduced capacity would affect the fuel savings potential by: (1) reducing the effective speed range where "Cross Connect" operation could be considered, and (2) requiring an SSGTG to supplement a limited "propulsion derived" generator output.

GENERAL CONCLUSIONS AND OBSERVATIONS:

- There are many options, tradeoffs and related issues to explore before one could commit to equipping the DDG Fleet with "Cross Connect" equipment. These include the availability of suitable power take offs, establishing the power levels, speed ranges, and electrical parameters yielding the best fuel savings potential, the selection of reliable, power dense machines, controls and transmission equipment, and its placement and operation such that current propulsion functionality is not compromised.

- The cost to develop, qualify, manufacture and install "Cross Connect" systems in the DDG Fleet could be substantial, especially with the challenges and constraints a retrofit imposes. The projected operating cost savings of a cross connect capability integrated with ship service, however, could be similarly great, and these would grow as the costs of fuel continues to escalate. A positive outcome of a Return on Investment (ROI) analysis would clearly be a necessary prerequisite to a decision to implement.

- Potential improvements in mission capability would add to the attractiveness of a fully integrated electrical "Cross Connect" capability. These could include a reduced low speed signature, increased range and time on station with a fixed fuel load, enhanced survivability resulting from additional power transmission options, and an increased ship service capacity to power upgraded combat systems.

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